FREQUENCY CHARACTERISTIC STUDY OF FILTERED-BACKPROJECTION RECONSTRUCTION AND MAXIMUM LIKELIHOOD RECONSTRUCTION FOR PET IMAGES

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Abstract

The Filtered-backprojection algorithm and statistical model based iterative algorithms such as maximum likelihood reconstruction are the two major classes of tomographic reconstruction methods. In this paper we studied the frequency characteristics of the filtered-backprojection method and the maximum likelihood method under noise free and noisy conditions. The experiment showed that the maximum likelihood algorithm may not generate superior image quality in terms of frequency characteristics.

I. INTRODUCTION

Tomographic image reconstruction has been an active research field in recent years. Filtered-backprojection method(FBP) and statistical model based iterative algorithms are the two major classes of reconstruction methods. FBP is widely used in clinical settings for its speed and easy implementation. Iterative algorithms take account the statistical nature of the acquired projection data and incorporate the physical model into reconstruction. Typical iterative methods include maximum likelihood and maximum a-posteriori algorithm. Since these two classes of algorithms are quite different in their approaches to tomographic image reconstruction, it is necessary to study and compare the performance of these two reconstruction methods.

There have been several studies on image quality and image noise of FBP algorithm[1],[2] and ML-EM algorithm[3],[4], but no comparison is made. In one recent study[5], Receiver Operator Characteristic method was used and the results revealed that iterative ML-EM algorithm doesn't show obvious diagnostic advantage over FBP method for cardiac nuclear medicine images. Wilson et al[6] used the covariance matrix to study the image noise magnitude and texture. Their findings are similar to that of reference 5. So far, all the previous work has been concentrating on the time domain property of the reconstructed images and the performance measures used are variance, covariance and mean square error. In this study, we study the frequency characteristics of both the FBP and ML reconstruction methods.

II. METHOD

A. Sinogram Simulation

We used simulated PET images of size 128 by 128 in this study. The test image consists of a ring pattern defined by the following equation,

$$g(x, y) = 0.5 + 0.5\sin\left(2\pi f\frac{\sqrt{(x-63.5)^2 + (y-63.5)^2}}{64}\right) \quad (1)$$

where $g(x,y)$ is the grey level of pixel (x,y) and f is the frequency of the ring pattern. From Equation 1, it can be easily seen that the line profile along each radial direction is a sine function shifted positively by 0.5. The positive shift avoids negative pixel level and the pixel grey level ranges between 0 and 1. The parameter f decides the frequency of the radial sine function. Since the radius is 64 pixel, a sine wave of frequency 16 will consist of 4 pixels each cycle. The test image was forward projected to get the sinogram. Independent pseudo-random Poisson noise was added to the noise-free sinogram.

B. Reconstruction

The image reconstruction was carried out by using the FBP and ML algorithms, for both the noise free and noisy sinograms. For the FBP algorithm, filter cutoff frequency is an important parameter to select. For this experiment, a Hann filter was chosen and the cutoff frequency from 0.1 pixel/cycle to 1 pixel/cycle was experimented. For the ML algorithm, the reconstructed image was saved for every 10 iterations up to 100 iterations.

C. Fourier Analysis

Fourier analysis was used to study the frequency characteristic of the reconstructed image. Eight line profiles along radial direction were obtained from the reconstructed image. Fourier analysis was performed on each line profile. The fundamental frequency percentage is calculated according to the following formula,

fundamental frequency percentage
= fundamental frequency power/total spectrum power

The calculated percentages of eight line profiles were averaged to get a final estimate.

III. RESULTS

The simulation were carried out for frequency of 2, 4, 8, and 16. The frequency characteristics of FBP and ML reconstruction under both noise free and noisy conditions were plotted in Figure 1 to Figure 4.

0-7803-2475-7/97 $10.00

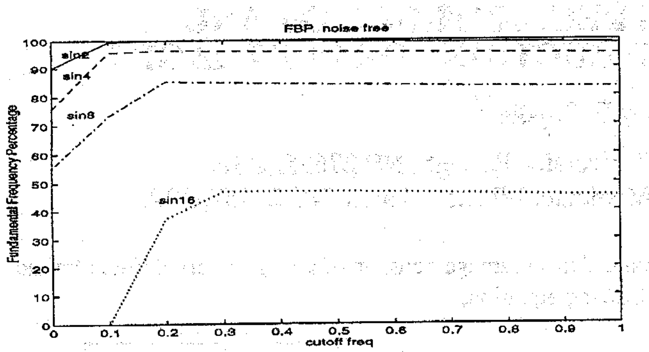

Figure 1 Frequency characteristics of FBP reconstruction under noise free condition.

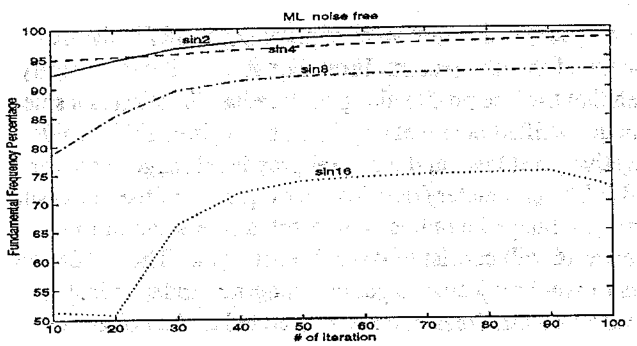

Figure 2 Frequency characteristics of ML reconstruction under noise free condition.

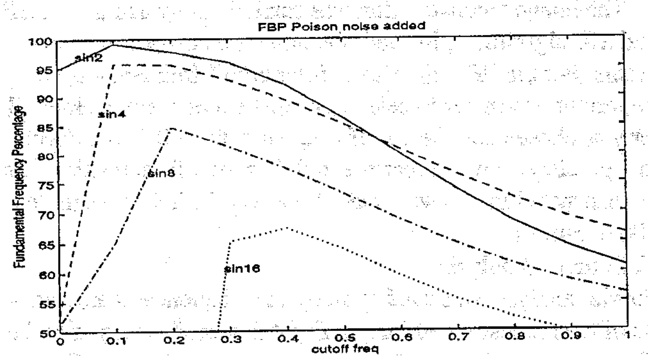

Figure 3 Frequency characteristics of FBP reconstruction under noisy condition (pseudo Poisson noise added).

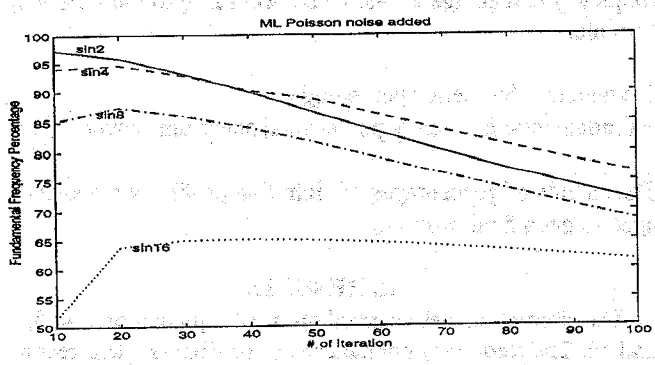

Figure 4 Frequency characteristics of ML reconstruction under noisy condition (pseudo Poisson noise added).

IV. DISCUSSION

Figure 1 and Figure 2 shows the frequency characteristics of FBP reconstruction and ML reconstruction under noise free condition. It can be seen that for the FBP method once the cut-off frequency is above the Nyquist sampling rate no obvious performance gain is achieved. The ML reconstruction displays a similar pattern. The performance increases initially with the number of iterations. However, after 40 iterations, limited performance improvement is made with the additional iterations.

Under noisy condition, the frequency performance behaves quite differently from that under the noise free situation. From Figure 3, it can be observed that the frequency performance reaches an optimum point and then drops rapidly with the increase in cutoff frequency. Similar behavior exists for ML reconstruction. Under the noisy condition, the ML reconstruction is unstable. With the increase of iterations after optimum point, the frequency performance deteriorates and the reconstructed image gets noisier. The experiment results suggest that the selection of the cutoff frequency for FBP reconstruction and the selection of the optimum iteration number for the ML reconstruction are very important under noisy under condition.

By comparing the frequency performance of the two algorithms, the ML algorithm doesn't show an obvious advantage over the FBP algorithm, under both noise-free and noisy conditions.

Since the reconstructed image is of small size of 128 by 128, the proposed frequency analysis method suffers from the aliasing effect, especially for frequency of 16. As a result, the simulation results can only give a very crude measure of the frequency characteristics of the reconstruction methods. More sophisticated method or analysis which takes account the aliasing effect need to be the focus of further study.

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